Chilling and Freezing Injury

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Chilling Injury: Many fruits, vegetables, and ornamentals of tropical or subtropical origin are sensitive to low temperatures (Paull, 1990). These crops are injured after a period of exposure to chilling temperatures below 10 to 15 °C (50 to 59 °F) but above their freezing points (Lyons, 1973; Wang, 1990). Certain horticultural crops of temperate origin are also susceptible to chilling injury (Bramlage and Meir, 1990). Those temperate crops, in general, have lower threshold temperatures, < 5 °C (41 °F). At these chilling temperatures, the tissues weaken because they are unable to carry on normal metabolic processes. Various physiological and biochemical alterations and cellular dysfunctions occur in chilling-sensitive species in response to chilling stress (Wang, 1982; Wang and Adams, 1982; Raison and Orr, 1990). When chilling stress is prolonged, these alterations and dysfunctions will lead to the development of a variety of chilling injury symptoms such as surface lesions, internal discoloration, water-soaking of the tissue, and failure to ripen normally (Saltveit and Morris, 1990). Often, products that are chilled will still look sound when remaining in low temperatures. However, symptoms of chilling injury become evident in a short time after they are removed to warmer temperatures. Fruits and vegetables that have been chilled may be particularly susceptible to decay. Weak pathogens such as *Alternaria* spp. that do not grow readily on healthy tissues can attack tissues which have been weakened by low temperature exposure (McColloch and Worthington, 1952; McColloch, 1962).

Both temperature and duration of exposure are involved in the development of chilling injury. Damage may occur in a short time if temperatures are considerably below the threshold level, but a product may be able to withstand temperatures a few degrees in the critical zone for a longer time before injury becomes irreversible. Maturity at harvest and degree of ripeness are important factors in determining chilling sensitivity in some fruits like avocados (Kosiyachinda and Young, 1976), Honeydew melons (Lipton, 1978), and tomatoes (McColloch et al., 1966). The effects of chilling are cumulative in some commodities. Low temperatures in transit, or even in the field shortly before harvest, add to the total effects of chilling that occur in cold storage.

Treatments which have been shown to alleviate chilling injury include: intermittent warming; high or low temperature preconditioning; CA storage; pretreatments with ethylene, abscisic acid, methyl jasmonate and other natural compounds; calcium or other chemical applications; hypobaric storage; waxing; film packaging; and genetic manipulation (Ryall and Lipton, 1979; Wang, 1993, 1994; Meir et al., 1996).

Chilling injury is discussed more specifically under each commodity. Many of the commodities susceptible to chilling injury are listed in Table 1 with threshold temperatures and some of the symptoms.

Table 1. Fresh produce susceptible to chilling injury when stored at low but nonfreezing temperatures.

Commodity	Lowest Safe Temperature °C	°F	Symptoms of injury when stored between 0 °C and safe temperature[1]
Apples-certain cultivars	2-3[2]	36-38	Internal browning, brown core, soggy breakdown, soft scald
Asparagus	0-2	32-36	Dull, gray-green, limp tips
Atemoya	4	39	Skin darkening, failure to ripen, pulp discoloration
Avocados	4.5-13[2]	40-55	Grayish-brown discoloration of flesh
Bael	3	38	Brown spots on skin

Bananas	11.5-13[2]	53-56	Dull color when ripened
Bean (lima)	1-4.5	34-40	Rusty brown specks, spots or areas
Bean (snap)	7[2]	45	Pitting and russeting
Breadfruit	7-12	45-53	Abnormal ripening, dull brown discoloration
Choyote	5-10	41-50	Dull brown discoloration, pitting, flesh darkening
Cranberries	2	36	Rubbery texture, red flesh
Cucumbers	7	45	Pitting, water-soaked spots, decay
Eggplants	7	45	Surface scald, alternaria rot, blackening of seeds
Ginger	7	45	Softening, tissue breakdown, decay
Guavas	4.5[2]	40	Pulp injury, decay
Grapefruit	10[2]	50	Scald, pitting, watery breakdown
Jicama	13-18	55-65	Surface decay, discoloration
Lemons	11-13[2]	52-55	Pitting, membranous staining, red blotch
Limes	7-9	45-48	Pitting, turning tan with time
Lychee	3	38	Skin browning
Mangos	10-13[2]	50-55	Grayish scaldlike discoloration of skin, uneven ripening
Mangosteen	4-8	39-47	Hardening and browning of the cortex
Melons			
Cantaloupe	2-5[2]	36-41	Pitting, surface decay
Honey dew	7-10	45-50	Reddish-tan discoloration, pitting, surface decay, failure to ripen
Casaba	7-10	45-50	Pitting, surface decay, failure to ripen
Crenshaw and Persian	7-10	45-50	Pitting, surface decay, failure to ripen
Okra	7	45	Discoloration, water-soaked areas, pitting, decay
Olive, fresh	7	45	Internal browning
Oranges	3[2]	38	Pitting, brown stain
Papayas	7	45	Pitting, failure to ripen, off-flavor, decay
Passion fruit	10	50	Dark red discoloration on skin, loss of flavor, decay
Peppers, sweet	7	45	Sheet pitting, alternaria rot on pods and calyxes, darkening of seeds
Pineapples	7-10[2]	45-50	Dull green when ripen, internal browning
Pomegranates	4.5	40	Pitting, external and internal browning
Potatoes	3[2]	38	Mahogany browning, sweetening
Pumpkins and hardshell squash	10	50	Decay, especially alternaria rot
Rambutan	10	50	Darkening of exocarp
Sweetpotatoes	13	55	Decay, pitting, internal discoloration, hardcore when cooked
Tamarillos	3-4	37-40	Surface pitting, discoloration
Taro	10	50	Internal browning, decay
Tomatoes			
Ripe	7-10[2]	45-50	Watersoaking and softening, decay
Mature-green	13	55	Poor color when ripe, alternaria rot
Water convolvulus	10	50	Darkening of leaves and stems
Watermelons	4.5	40	Pitting, objectionable flavor

[1]Symptoms often become apparent only after removal to warm temperatures, as in marketing.
[2]See text.

Freezing Injury: The recommended storage temperatures for commodities that are not susceptible to chilling injury are as low as possible but slightly above the freezing point. Freezing injury occurs when ice crystals form in the tissues.. Cultivars, locations, and growing conditions may affect the freezing point. To be on the safe side, the highest temperature at which freezing of a specific commodity may occur should be used as a guide for recommending the optimum storage temperature. More detailed discussion of freezing points and factors affecting them can be found in McColloch (1953), Whiteman (1957), and Parsons and Day (1970; 1971). The most common symptom of freezing injury is a water soaked appearance. Tissues injured by freezing generally lose rigidity and become mushy upon thawing.

The susceptibility of different fresh fruits and vegetables to freezing injury varies widely. Some commodities may be frozen and thawed a number of times with little or no injury, whereas others are permanently injured by even a slight freezing. All fruits and vegetables can be categorized into three groups based on their sensitivity to freezing: *most susceptible*, those that are likely to be injured by even one light freezing; *moderately susceptible*, those that will recover from one or two light freezings; and *least susceptible*, those that can be lightly frozen several times without serious damage. Table 2 shows the relative susceptibility of a number of fruits and vegetables to freezing injury.

The freezing point of the commodity is no indication of the damage to be expected by freezing. For example, both tomatoes and parsnips have freezing points of -1.1 to -0.6 °C (30 to 31 °F), but parsnips can be frozen and thawed several times without apparent injury, whereas tomatoes are ruined after only one freezing. The severity of freezing injury is influenced by a combination of time and temperature. For example, apples that would be injured little by exposure to temperatures slightly below the freezing point for a few days would be severely injured by just a few hours of exposure to -7 to -10 °C (19.4 to 14 °F). The susceptibility to freezing injury is not necessarily similar for the same type of fruit or vegetable. For example, leafy lettuce is very susceptible to freezing injury, whereas some other leafy vegetables, such as kale and cabbage, can withstand several light freezings without serious injury.

When left undisturbed, most fruits and vegetables can usually be cooled one to several degrees below their freezing point before they actually freeze. This cooling without freezing is known as under-cooling or super-cooling. They may remain under-cooled for several hours, but they will usually start to freeze immediately if jarred or moved. If permitted to warm above the freezing point, many commodities that were under-cooled may escape having ice crystals form in them. For example, potatoes are very sensitive to freezing damage but they have been shown to under-cool for a short time to -3.9 °C (25 °F), about 3 °C (5.4 °F) below their freezing point) and then can be carefully warmed with no freezing symptoms occurring (Hruschka et al., 1961).

Plant tissues are very sensitive to bruising while frozen, and this sensitivity is another reason for leaving commodities undisturbed until they have warmed. Selecting a suitable thawing temperature involves a compromise. Fast thawing damages tissues, but very slow thawing such as at 0 to 1 °C (32 to 33.8 °F) allows ice to remain in the tissues too long and causes injury. Research on the rate of thawing has suggested that thawing at 4 °C (39.2 °F) causes the least damage for most commodities (Lutz, 1936). Even though a number of fruits and vegetables are somewhat tolerant to freezing, commodities recovered from freezing often have shorter storage life and are more susceptible to invasion by microorganisms. For example, apples that recover from freezing are softer than normal fruit, and carrots that have been frozen are especially subject to decay. Therefore, it is desirable to avoid subjecting fresh produce to freezing temperatures.

Table 2. Susceptibility of fresh fruits and vegetables to freezing injury.

Most susceptible	**Moderately susceptible**	**Least susceptible**
Apricots	Apples	Beets
Asparagus	Broccoli	Brussels sprouts
Avocados	Carrots	Cabbage, mature and savory
Bananas	Cauliflower	Dates
Beans, snap	Celery	Kale

Berries (except cranberries)	Cranberries	Kohlrabi
Cucumbers	Grapefruit	Parsnips
Eggplant	Grapes	Rutabagas
Lemons	Onion (dry)	Salsify
Lettuce	Oranges	Turnips
Limes	Parsley	
Okra	Pears	
Peaches	Peas	
Peppers, sweet	Radishes	
Plums	Spinach	
Potatoes	Squash, Winter	
Squash, Summer		
Sweetpotatoes		
Tomatoes		

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